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THE CONDITIONS OF THE UNIPOLAR STIMULATION IN PHYSIOLOGY AND THERAPEUTICS.

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By electrotonus is meant that condition of altered irritability of a nerve which is produced by the flow through it of a current of electricity; and this altered irritability manifests itself by increased or diminished reaction of the nerve to the various stimuli, whether mechanical, physical, or chemical, which may be applied to it.

Du Bois Reymond, who introduced this word in physiology,[1] at first implied by it merely the changes in the electromotive manifestations of the nerve which accompany the changes in its irritability. A clear recognition of the latter, says Hermann,[2] does not occur in any of the older physiologists, nor in Du Bois Reymond's great work. Valentin[3] was the first to show that the polarised portion of the nerve does not readily transmit impulses from above; and that the irritability of the part below it is diminished when the polarising current is centripetal, or ascending. Eckhard[4] observed that when the current is descending, an opposite condition of augmented irritability below the polarised portion existed. Hence he formulated as a general law that irritability is increased beyond the kathode, or negative pole; diminished beyond the anode, or positive pole.

Pflüger, by a series of admirable experiments, eliminated all the sources of error which beset this difficult field of inquiry, and resolved all the phenomena into his dictum:—The irri-

1 'Untersuchungen über thierische Elektricität,' 1848, 1849.
2 'Handbuch der Physiologie,' vol. ii. part i. p. 41, 1879.
3 'Lehrbuch der Physiologie,' 2nd Ed., 1848.
4 'Beiträge zur Anatomie und Physiologie,' 1855.

tability is increased on either side of the negative electrode, diminished on either side of the positive. Or, in other words, the region of the kathode is thrown into a state of katelectrotonus, that of the anode of anelectrotonus. In the intra-polar region the two zones meet at a point of indifference, where irritability remains normal. This point is the nearer to the kathode the stronger the current, and *vice versâ.*

Whenever a galvanic current of sufficient strength is made or broken through a portion of a motor-nerve, a contraction in the muscle occurs. It was one of the earliest observations made that a contraction appears earlier (i. e. with a weaker current) when the current is descending (i. e. with the kathode peripherally and the anode centrally placed) than under the opposite conditions (Pfaff, in 1795). Ritter (1798), and Nobili (1829), with a host of other observers, confirmed this fact, and elaborated what are known as "laws of contractions;" that is, tables of the reactions which the exsected nerve yields to make and break off the ascending and descending currents, at different stages of its diminishing vitality. That such researches must have been limited is made at once evident by the consideration that the first constant galvanic element was invented in 1836 by Daniell. Yet on the whole it is possible to reconcile the main results obtained up to the time of Du Bois Reymond,[1] with those of Heidenhain,[2] who substituted "stages of current strength" for the "stages of irritability" of his predecessors. But it would be transgressing our present limits to delay on these topics, and we at once reach Pflüger, to whom we owe also the expression of the phenomena of nerve-reactions to different current-strengths in their simplest formula :—

Current.	Ascending Current.		Descending Current.	
	Make.	Break.	Make.	Break.
Weak	Contraction	Rest	Contraction	Rest
Medium	Contraction	Contraction	Contraction	Contraction
Strong	Rest	Contraction	Contraction	Rest (or weak C.)

[1] Loc. cit. [2] 'Archiv für physiologische Heilkunde,' 1857.

Pflüger did not remain content with leaving his law of contraction and his law of electrotonus side by side; but by a further induction reduced the one to the other, and showed in the happiest manner that a nerve is stimulated by the apparition of katelectrotonus, and the disappearance of anelectrotonus; that is, by the passage of a lesser to a greater degree of irritability. In other words, that the stimulation occurs at one electrode only: at the kathode on closing, at the anode on opening the current. He completely exposed the fallacy of the views of the previous writers, who had all explained by the differences in the direction of the current itself the different results they obtained by the making and breaking of ascending and descending currents; and showed that it was the relative position of the two poles *to one another*, and not to the direction of the nerve-impulse, that was the condition upon which depended the variations in the results obtained.

His argument was based on the facts that the closure of the current is a more powerful stimulant than the opening; that anelectrotonus takes more time and stronger currents to develope than katelectrotonus; and that immediately after the opening of the polarising current the katelectrotonic zone passes into a condition of transitory diminution of irritability, or "negative modification," whilst the anelectrotonic zone passes immediately into one of increased irritability, or "positive modification." Thus it becomes clear why weak currents excite the nerve at the closure only: anelectrotonus is not sufficiently developed by them to cause a contraction on its disappearing, nor to prevent the transmission of the katelectrotonic stimulus from above. Strong currents, on the other hand, develop a powerful anelectrotonus, and negative variation, which arrest the make, and break impulse from above respectively. Medium currents allow a sufficient anelectrotonus to set in which will stimulate on disappearing; but not to arrest the central katelectronic impulse, whilst the negative modification of the katelectrotonic region also is too weak to arrest the stimulation produced by the disappearance of anelectrotonus on the breaking of the descending current.

In presence of the clear fact that, according to Pflüger, stimulation is produced at the kathode on closing, at the anode on opening of the current, and at the former more readily than at the latter, it is difficult to see how many electrotherapeutical writers have been able to continue speaking of the results obtained by physiologists as dependent on the direction of the current with reference to the nerve; and to place their so-called "polar method" in a position of antagonism to the "physiological method."[1] In the latter, it is true, in order to eliminate many disturbing elements, such as the influence of the central organs, the action of derived currents, &c., the nerve is usually exsected, and both poles applied to it directly; but apart from these differences of manipulation, there is no such fundamental difference between the two methods as has been claimed. Let us first throw a retrospective glance into the origins of that polar method, the subject of so many misunderstandings and passionate recriminations.

Among the earlier observers we come across but few and vague data concerning the effects of the galvanic current on the living body. Ritter[2] noticed that a strong current flowing from hand to hand produced in the arm up which it flows a sensation of increased mobility, and *vice versâ*. Matteucci[3] repeated the observation of Nobili, that tetanised frogs' legs were quieted by an ascending current, and even proposed therapeutical applications of this fact.[4] Valentin[5] is the first to make an explicit statement on the subject. He finds that in the living animal contraction occurs most readily on closing the current, whatever be its direction. Fick and Orelli[6] found the same happen in their experiments on the ulnar nerve in man. Schiff[7] puts down as a law that "contraction occurs in the living subject on making the current in

[1] Hermann says (loc. cit. vol. ii. p 63): "Pflüger the first showed that stimulation of the nerve occurs at one electrode only, on making the current at the kathode, on breaking it at the anode"; and recognises Chauveau's independent discovery of the same fact. Biedermann, by the way ("Uber die polaren Wirkungen des elektrischen Stromes im entnervten Muskel," 'Sitzungsberichte der K. K. Akad. d. Wissenschaften,' vol. lxxix. p. 289), has successfully demonstrated the polar effects on curarised muscle.

[2] 'Beiträge zur nähere Kenntniss des Galvanismus,' Jena, 1802.

[3] 'Essai sur les Phénomènes électriques des Animaux,' 1840.

[4] Cf. 'Traité des Phénomènes electro-physiologiques,' chap. ix., "Usage thérapeutique du Courant continu." 1844.

[5] Loc. cit.

[6] 'Wiener Medicinische Wochenschrift,' 1856.

[7] 'Lehrbuch der Nervenphysiologie,' p. 80, 1856.

either direction, but no contraction on breaking it," adding, it is true that in his experiments he never closed the current for more than five seconds. Claude Bernard, whose classical lectures appeared at the same time,[1] says that "a nerve placed in normal organic conditions, fit to transmit voluntary impulses, gives only one contraction, which occurs on closing the current, whatever be its direction," adding that deviations from this law depended on the mutilation of the nerve.[2] This point has been lately taken up by Rumpf,[3] chiefly from a clinical point of view. He shows that the apparition of the A.O.C. is delayed by the influence of the central organs and hastened by the removal of this influence. There is thus a qualitative disturbance of the normal galvano-nervous formula, which has escaped notice hitherto, owing, probably, to the shortness of the period at which it is recognisable—a few days only, immediately after the injury. The subject deserves further investigation, but much care is required to avoid fallacies. It is probably owing to the influence of Remak[4] that electro-therapeutists have had so much difficulty in realising the full bearings of Pflüger's conclusions. Remak's researches on the effects of the galvanic current on the nerves in the living subject were mainly directed to the phenomenon of "galvanotonus," that is, of contraction during the continuous flow of the current. This he found to be more marked when the current was descending.

Grapengiesser, as early as 1801,[5] had expressed himself clearly to the effect that the negative pole was the more effectual of the two, both at the closing and during the passage of the current. Remak takes extraordinary pains to show that this superiority of the kathode, due to its chemical properties, exerts no influence on the results of the transverse stimulation of nerves. If, for instance, the two poles are

[1] 'Leçons sur la Physiologie du Système nerveux,' vol. i., 1858.

[2] Similar observations were made by Pflüger, Bezold, and Rosenthal. See Meissner's 'Bericht' for 1858. Romanes (Proc. Roy. Soc., 1876 and 1877) has measured the changes in the excitability of the frog nerve produced by injury. Thus, before section A.C. = 90; K.C. = 100; A.O. = 14; K.O. = 6; whilst after section A.C. = 140; K.C. = 300; A.O. = 195; K.O. = 14.

[3] 'Archiv f. Psychiatrie,' vol. viii. p. 567.

[4] 'Galvanothérapie,' 1859.

[5] Quoted by Remak, loc. cit., p. 102.

placed on the temples, it is noticed that contractions are more readily obtained on the side of the kathode; but this is probably due to the fact that the current there is "ascending," for the current avoids the resisting bones, and passes round about the forehead. Even were this not the case the phenomenon could be readily explained by the assumption that a nerve is more readily stimulated by a current flowing transversally through it from its inner to its outer aspect than in the opposite direction![1]

The method usually spoken of in electrotherapeutics as "Brenner's polar method" was, so far as its physiological basis is concerned, fully described by Baierlacher in 1859.[2] Before entering upon this subject, I may be allowed to offer a few remarks on the impropriety of the word "polar." By it is implied that the method rests upon a recognition of polar, instead of directional, influences, and is meant to distinguish it from the so-called "physiological" method. But the truth is, that, as we have already stated, in physiology, since Pflüger, it is to the specific action, chemical or otherwise, of each pole that the effects of the current are attributed. The physiological is, therefore, a polar just as much as the therapeutical method; the first is *bi*polar, the other *uni*polar. By these terms we simply mean that either both poles or only one pole is applied to the nerve. I need hardly point out that the term unipolar, taken in this sense, has nothing to do with the unipolar effects of induction discovered by Du Bois Reymond in 1845,[3] and since then studied by a large number of observers.[4]

In order to let the reader judge for himself how far Baierlacher had anticipated Brenner, I quote some abstracts:—

"The unipolar method of nerve-stimulation adopted by me gives us the opportunity of observing the separate action of each pole on the nerve, whereby we attain the peculiar conclusion that the same phenomena are produced which we are accustomed to consider as depending upon the direction

[1] Sounder views, however, prevail in Remak's later writings, e.g., in his 'Leçons sur l'Application du Courant continu.' Paris, 1865.

[2] 'Zeitschrift für rationelle Medicin,' series III., vol. v., p. 233. Compare Meissner's abstract in 'Bericht,' ibid., vol. vi. p. 442.

[3] 'Untersuchungen,' vol. i. p. 423.

[4] See Hermann, loc. cit., p. 86.

of the current. The positive pole on the nerve gives us the results of the 'ascending,' the negative of the 'descending,' current."[1]

The nerve chosen by Baierlacher for his first experiments was the peroneal, near the head of the fibula; and the result of numerous experiments was that,[2] "with the negative pole on the nerve, the closure contraction was very strong, the opening contraction absent, or exceedingly feeble. With the positive pole to the nerve, the opposite took place, the closure contraction being absent or very weak, the opening contraction strong." Thus the order was K.C.C., A.O.C., A.C.C., K.O.C.: a more accurate statement than that of Brenner, who places A.C.C. before A.O.C., owing probably, as we shall see, to a want of care in applying his electrode.[3]

The author further states[4] that "there can be no question about a difference in the direction of the currents" in his experiments, as the contractions appeared in the same order whether the indifferent electrode was placed above or below the other. He displays considerable acumen in the remark that, even with these changes in the position of the indifferent electrode, the upward or downward direction of the current can be but of secondary influence, compared with that exerted by the very different densities of the current at its points of entrance into, and exit from, the nerve respectively.

Baierlacher also repeated the experiment of Fick with both poles on the ulnar nerve, and came to the conclusion that the order of contractions was—

Current.	Descending.	Ascending.
Closure.	Very Strong.	Strong
Opening	Absent or Weak	Moderate

A result which coincides with the view that the anodal reactions of the unipolar method correspond with the "ascending," the kathodal reactions with the "descending," reac-

[1] Page 253.
[2] Page 249.
[3] Or, at least, to his using a too large 'different' electrode.
[4] Page 251.

tions of the bipolar method. This point is recognised by Meissner.[1]

Chauveau, at the same time, following an entirely different train of thought, came to similar conclusions: a result all the more meritorious that he worked in complete ignorance of all that was being done in Germany, and laboured under serious misconceptions, such as an imaginary influence of electrical "tension" and of "extra-currents." His experiments[2] were made with Leyden jars, induction coils, and galvanic batteries. The two former bring about contractions more readily at the negative than at the positive pole. On making a weak galvanic current, stimulation occurs at the negative pole only; the direction of the current has no influence whatever. For instance, when the poles are on the sciatic plexus and the lower part of the sciatic nerve, contractions occur in the thigh and leg when the cathode is on the plexus; in the leg only, when it is on the nerve.

The opening contraction occurs, under similar conditions, at the positive pole. In every case the indifferent pole may be applied to any part of the body without changing the results. Space does not allow me to indicate more than the general results of Chauveau's elaborate papers.[3] A good abstract of his researches has been given by Meissner, who adds[4] that these results coincide with those of Baierlacher,

[1] Loc. cit.

[2] "Théorie des effets physiologiques produits par l'électricité transmise dans l'organisme animal à l'état de courant instantané ou de courant continu," 'Journal de la Physiologie,' 1859, pp. 490, 553, 1860, pp. 52, 274, 458, 534, ff. See also Meissner's 'Bericht,' in 'Zeitschrift für rationelle Medicin,' 1860, p. 554.

[3] I cannot here pass under silence Chauveau's latest contributions to the subject of unipolar stimulation. ('Comptes Rendus de l'Académie des Sciences,' 1875, 1876, vols. lxxxi. pp. 779, 824, 1038, 1193, and lxxxii. p. 83). In a series of notes to the Academy he has formulated a number of propositions which are mostly in direct contradiction to all the received views, and his own former results. His recent experiments have been made both on frogs' and mammalians' nerves. To discuss them here is impossible, as they are but briefly described; but they will have to be carefully controlled. He reaches the astonishing conclusion, that for every motor-nerve there exists a current-strength (usually very weak) which gives to both poles the same degree of activity. Below it is the negative pole, above the positive, which preponderates. For sensory nerves it is the opposite that holds.—What precedes applies to the *closure* of the current. On opening also, Chauveau finds the positive pole the more active. His results are embodied in a number of tracings and tables of curves.

[4] Loc. cit., p. 455.

and with Pflüger's theory that stimulation is produced at the appearance of katelectrotonus (= closure contraction when the kathode is on the nerve), and at the disappearance of analectrotonus (= opening contraction when the anode is on the nerve).[1]

The untiring zeal and brilliant success of Brenner in applying the unipolar method to the practice of electro-diagnosis, his success in upsetting the obsolete views of Remak and his followers,[2] are quite sufficient to secure him a prominent place in the history of the question; though Pflüger's law, rightly understood, on one side, and the results of Baierlacher and Chauveau on the other, deprive him of the priority which seems generally to be conceded to him. It was only in 1862[3] that he first published his "discovery" that the closure contraction depended upon the negative pole, the opening contraction upon the positive. In his great work[4] he has collected a vast array of experiments and illustrations in support of his views. The first volume is devoted to the application of the unipolar method to the acoustic nerve, which gives a very pure series of reactions in the normal condition, responding to the cathodal closure (and duration) and anodal opening only. He endeavours to base a rational system of electro-otiatrics on this result. In the second volume he describes the apparatus and manipulations neces-

[1] I think I may fairly claim as supporting the main argument of this paper the results obtained by Morat and Toussaint ('Comptes Rendus de l'Académie des Sciences,' 1877, vol. lxxiv., p. 503), with reference to the electrotonic state of nerves excited on the unipolar method. These observers found that the modifications were of the same order on both sides of the point of application of the electrode. When the kathode was applied, the modification was positive at both ends; when the anode, the modification was negative. Now, in the usual bipolar application, the modification at each end is of the same name as the neighbouring pole. The authors explain the results of the unipolar excitation by saying that the current follows the nerve in two directions; opposed to the natural nerve current in one case, concordant with it in the other; hence the negative and positive modifications. But is it not simpler to assume that it is the virtual anodes or kathodes, on either side of the actual electrode, which produce the phenomenon? When the positive pole is on the nerve, the two virtual kathodes will naturally call forth the negative modification at each end; and the opposite will happen when it is the negative pole which is in contact with the nerve.

[2] See, for instance, Benedikt, 'Elektrotherapie,' 1st Edition, 1866, so unsparingly criticised by Brenner in his 'Untersuchungen,' vol. ii. p. 208, ff.

[3] 'St. Petersburger Medicinische Zeitschrift,' vol. iii.

[4] 'Untersuchungen und Beobachtungen auf dem Gebiete der Elektrotherapie,' Leipzig, 1868–69.

sary to operate successfully, discusses the relations of the "polar" to the "physiological" methods, and makes a substantial contribution to the art of electro-diagnosis.

The effect of Brenner's work was to call forth a controversy as violent as it was useless, but it stimulated also the zeal of a large number of workers in the field. Though the din and dust of the battle caused the loss of much time and temper, there gradually arose clearer views, and valuable results were obtained. The question of the possibility of demonstrating the phenomena of electrotonus in the living human nerve occupied the attention of several observers. First, Fick,[1] whose results were negative, then Eulenburg[2] and Erb[3] appear in the field. Eulenburg, applying the galvanic current to an accessible nerve, such as the peronæus, ulnar, &c., tested its irritability by means of an induced current below the point of application. His results were in accordance, apparently, with those obtained on the exsected frog's nerve; and he found increased or diminished irritability when he produced descending extrapolar katelectrotonus or anelectrotonus. Erb was not so successful in his first experiments, and found a complete inversion of the phenomena, though he followed a method similar to Eulenburg's. Helmholtz[4] thereupon made an important suggestion, which seems to me to contain, as in a germ, the solution of the main difficulties encountered in the experimentation on the living body, and which will be developed further on. He said that Erb's paradoxical results might be due to the fact of the electrical diffusion, which in the immediate neighbourhood of the electrode must be sufficiently considerable to justify the assumption that it there acts as an opposite pole. Acting upon this supposition, Erb tested the condition of the nerve immediately under the electrode, and found it coincide with that obtaining in physiological experiments. The results of Samt[5] are interesting

[1] 'Medicinische Physik,' 1866.

[2] "Ueber elektronisirende Wirkung bei pereutoner Anwendung des constanten Stromes auf Nerven und Muskel," 'Deutsches Archiv für klinische Medicin,' vol. iii. p. 117 (1867).

[3] 'Ueber elektrotonische Erscheinungen am lebenden Menschen,' ibid. p. 513; and 'Galvanotherapeutische Mittheilungen,' ibid., pp. 238 and 333.

[4] In an oral communication to the Naturhistorisch-Medicinisch Verein meeting at Heidelberg, 1867.

[5] 'Der Elektrotonus am Menschen,' Berlin, 1868.

chiefly on account of his conclusion that many of the inconsistencies among the results obtained on the human subject are due to morbid conditions of the nerves : a view supported by the fact that the gradual exhaustion of a frog's nerve is a frequent cause of fallacy in experiments, and that the ventral organs exert a marked influence in the time of apparition of the several reactions.

Brückner's results[1] do not throw much further light upon the subject; but the method he used suggested to Runge[2] a series of experiments which are described in a very able paper. This method consisted in intercalating in the circuit of the polarising current the secondary coil of the testing instrument. Brückner found that when the two currents moved in opposite directions the effect was diminished at the negative pole of the induced current especially. Runge performed a series of ingenious experiments, the result of which goes far to prove that in all anterior electrotonic experiments the summation of effects of the two currents must be the real cause of the phenomena, and not the altered irritability of the nerve. Ziemssen[3] coincides with this view, which he supports by experiments of his own. But he justly condemns the sweeping assertions of Runge, who, forgetting the results obtained in physiological experiments by irritating the nerve with chemical agents, would explain the whole question of electrotonus by a mere antagonism or combination between the polarising and testing currents.

The only experiments on electrotonus in the living man where due care was taken to avoid the innumerable sources of fallacies which beset all such attempts, are those of Cyon,[4] made in 1868. By dint of trouble and care, he obtained normal results in a *few* cases : a significant fact, and which, in itself, speaks volumes against the basing a therapeutical system upon the supposed electrotonic influences of the rough

[1] "Ueber die Polarisation des lebenden Nerven in Menschen," 'Deutsche Klinik,' 1868 and 1871.

[2] "Der Elektrotonus am lebenden Menschen," 'Deutsche Archiv für klinische Medicin' (1870), p. 356.

[3] 'Die Electricität in der Medicin,' 4th Edit., pp. 63 ff.

[4] 'Principes d'Électrothérapie,' Paris, 1873. At the same time I fully agree with all that Erb says of this work in his severe review of it. (Virchow's 'Jahresbericht' for 1873.)

and ready proceedings usual in medical applications of electricity. Cyon experimented on the ulnar nerve; he found it necessary to fix the arm in a plaster of Paris mould; applied the polarising electrodes over points where the nerve was superficial, and tested the extrapolar descending electrotonus by means of induction shocks. The electrotonic condition was expressed in terms of the contractions of the adductor pollicis; their amplitude being registered on a revolving drum by means of a lever attached to the thumb. The cases in which he was unsuccessful he explains partly by morbid conditions of the nerve, partly by the influence of the central organs; but apparently ignores Helmholtz's explanation, which is of far greater importance, that the disturbing element lies in the irregular diffusion of the current from the nerve among the surrounding tissues.

Hitzig[1] in a valuable contribution, unfortunately unfinished, among other points discusses the reactions of the acoustic nerve to the galvanic current. It is the only nerve of the body on which we obtain reaction to anodal opening and cathodal closure *only*. The reason given for this fact by Hitzig is not only satisfactory, but most suggestive. The deviations from the typical formula, he says, occurring in unipolar excitation of other nerves, is due to their being surrounded by good conductors, as suggested by Helmholtz, with reference to Erb's experiments on electrotonus. Now the acoustic nerve is surrounded by bone, a bad conductor, and ends in a substance homogeneous to itself; therefore the whole of it may be thrown into a state of anelectrotonus or katelectrotonus: hence the purity of its reactions. I fully agree with Hitzig in his various strictures on Brenner's views; but think with Erb[2] that it is a fallacy to argue to the absolute non-existence of polar effects from the inefficacy of transverse electrisation of the nerve. May it not be assumed that under such conditions the two opposite polar actions are in equilibrium and neutralise one another?[3]

[1] "Ueber den relativen Werth einiger Elektrisations Methoden," 'Archiv für Psychiatrie,' vol. iv. p. 159 (1874).

[2] "Ueber die Anwendung der Elektricität in der inneren Medicin," 'Volkmann's Vorträge,' No. 46.

[3] The possibility of transverse stimulation of nerves is at present the subject

Filehne[1] has laboured very hard to reconcile the "therapeutical" and "physiological" methods. Considered from a general point of view, such a reconciliation appears unnecessary: impossible indeed from a more special standpoint, since the very essence of the bipolar method consists in acting on the isolated nerve with the two poles at their full undivided power; whilst that of the unipolar method consists in eliminating, as much as possible, by scattering it, the effect of one of the poles. Pflüger having shown that contraction depends on purely polar effects, the problem was rather to explain how it is that with the unipolar method the anodal closure usually preceded the anodal opening contraction, and how anodal closure and cathodal opening contractions occurred at all. Filehne has done this but very imperfectly. He shows that in unipolar excitation the current diffuses both up and down the nerve; and that the results were as if half the neutral pole was placed above, and half below the active pole. We readily grant this, but then are at a loss to understand how he ever could obtain results comparable to those of the bipolar method, as he never opposed but the inferior half of the divided to the whole undivided pole. In fact, his experiments repeated by Burkhardt[2] led this observer to different results. As to his experiments with excessive currents—8–30 cells to a frog's nerve, 50 cells to a rabbit's!—in which he obtained anodal make and kathodal break contractions only, we may safely assume that this phenomenon was rather due to injury to the nerve from the powerful chemical action, and hardly adducible as corresponding to Pflüger's third stage. At any rate Burkhardt did not find it at all constant in its occurrence. It must be noted, by the way, that Filehne does not mention how far he confirmed his data—apparently obtained from very few experiments—by an extended series of controlling tests, a very necessary precaution in this field of inquiry. It has also to be proved that the greater irritability of the upper part of the exsected frog's nerve is not the result of mutilation, before

of a controversy between Tschiriew, who has affirmed it ('Archiv f. Physiologie,' 1877 and 1879), and Hermann, who denies it ('Handbuch,' 1879, vol. ii. p. 80).

[1] "Die electrotherapeutische und die physiologische Reizmethode," 'Deutsches Archiv für klinische Medicin,' vol. vii., p. 575, 1870.

[2] 'Physiologische Diagnostik der Nerven Krankheiten,' 1875.

assuming, as he and others have done, that the anodal stimulation corresponds to the descending, and cathodal to the ascending current. Baierlacher and Meissner, as stated above, held an opposite view.[1] Filehne's views of a "peripolar" stimulation, it may be added, remind one very much of the experiments of Rousseau, Lesure, and Martin Magron,[2] in illustration of the fallacies in the results of Longet and Matteucci, due to the existence of derived currents in the undivided nerve. Chauveau[3] had also shown that the effects of lifting out the nerve on the electrode, and so exciting it by a true "peripolar" current, whilst the other was applied to the limb, were the same as those of unipolar excitation of the nerve *in situ.*

In much of what has been written on the subject of unipolar stimulation, there seems to me to underlie a fundamental fallacy: I mean a confusion between positive and negative *potential,* and positive and negative *pole* (or anode and kathode). It is quietly assumed that when, for instance, an electrode is held in each hand, one of the arms is under an anodal, the other under cathodal influence; but the fact is, they are simply at potentials different, positively and negatively, from that of the earth.[4] It cannot too strongly be dwelt upon that potential means simply *level,* and differences of electrical potential differences of electrical level, without which a flow of electricity is impossible. But by anode and kathode we mean a totally different thing; we mean the point of entrance of the current into, and its point of exit from, an electrolyte, that is, a conductor in which electrolysis is set up. Further, in a circuit composed of several electrolytes, the boundary between each pair of electrolytes acts as kathode to the one which the current leaves, and as anode to the one which it enters.

It is clear then that in sending a current through a composite electrolyte, such as the human body, there can be no question of exclusive localisation of "polar" effects. At every point where the current passes from one liquid, one tissue, or one cell, into another, there is an anode and a kathode, each endowed with its full chemical and physiological properties.

[1] See Heidenhain, 'Meissner's Bericht,' 1857, p. 420.

[2] 'Gazette Médicale,' 1858; see also Bernard's 'Leçons sur la Physiologie du Système nerveux,' vol. i. p. 180.

[3] Loc. cit. [4] De Watteville, 'Introduction to Medical Electricity,' p. 111.

Let us consider what takes place when the positive electrode is applied to the skin over a nerve. The current passes through the epidermis and subjacent layers, and part of it enters the nerve-fibres; at this point we have what I call the *virtual anode*. The greater portion of the electricity which has entered the nerve leaves it almost immediately, on account of the better conductivity of the surrounding tissues: these points of emergence form the *virtual kathode* of the nerve. The relative density of the current at the virtual electrodes depends upon its diffusion; and this again is regulated entirely by physical conditions, viz. the relative position of the actual electrodes, and the relative conductivity of the nerve and surrounding tissues.[1]

Now, it is upon the action of the virtual electrodes that the phenomena of electrotonus, and hence of contraction, depend; and this consideration is, in my opinion, capable of explaining all the apparent anomalies, without any reference to a "peri-polar" direction of current, or any such hypothesis. The appearance of katelectrotonus is a more powerful stimulant than the disparition of anelectrotonus. Hence when the positive pole is over the nerve, though the virtual anode is denser[2] than the virtual kathode, the latter will overtake the former, and produce a closer contraction, equal to or stronger than the opening contraction, as soon as $\frac{D^-}{D^+}$ is equal to or greater than $\frac{S^+}{S^-}$ (when D. and S. stand for density and stimulating energy of anode and kathode respectively). Hence also the great preponderance of kathodal closure over kathodal opening: the latter labours under double disadvantage, since the virtual anode now, besides its inherent inferiority, is not sufficiently dense to exert much influence. Brenner, in presence of the kathodal opening and anodal closure contractions, tried to explain them away by a mutual "overtaking" (übergreifen) of both poles.

[1] If a nerve lie isolated at any point of its course, and placed in contact with an electrode whilst the circuit is closed at any part of the body, the virtual electrodes of the opposite name will be at the points where the nerve emerges from the surrounding tissues.

[2] And hence more effective: Du Bois Reymond's law.

In proportion as we, by the position of the actual electrode, can increase the difference of density between the two virtual electrodes we obtain purer polar effects. It is in this sense that Hitzig's explanation of the acoustic reactions must be taken. With most nerves of the body it is impossible even to approximate the normal formula; but in a few cases (such as with the ulnar at the elbow and wrist, and the peroneal at the head of the fibula) we obtain results which go far to prove my theory. If, for instance, one pole, being as usual on a distant, "indifferent" part of the body (the back, the sternum, &c.), the "differential" electrode is applied over the ulnar, close to the wrist, we obtain a series of contractions, K.C.C., A.O.C., A.C.C. (K.O.C.). Here we remark that A.O.C. $>$ A.C.C. as it should be; but if we push the electrode a little higher up, where the nerve is immediately surrounded by good conductors (muscle and blood-vessels), we find A.O.C. $=$ A.C.C., and finally A.O.C. $<$ A.C.C. The explanation of this fact, according to me, is simply that in the first case the virtual kathode is spread over a greater length of the nerve, hence not so dense and effective; in the second, the current leaving the nerve immediately after it has entered it, the virtual kathode is, though not so dense as the virtual anode, still sufficiently so to make up the difference by its physiological preponderance.

Brenner gives synoptical tables intended to prove the parallelism between the "physiological" and his "polar" method; but with the exception that he shows that "apparition of katelectrotonus" is synonymous with "kathodal closure," and "disparition of anelectrotonus" with "anodal opening," these tables are useless. It would be better to tabulate the different conditions obtaining in the two methods. For instance:—

Physiological or Bipolar.	*Therapeutical or Unipolar.*
The nerve is mutilated and exposed, in direct contact with the electrodes. It is separated from its centres, and from its blood-supply.	The nerve is entire and lies in its physiological and anatomical relations, and is separated from the actual electrode by the skin and other tissues.
The actual and virtual electrodes are one, and the current at each usually of equal and known density. They are placed one above the other.	The current at the virtual electrodes is of different and unknown densities; the whole of one virtual electrode may roughly be said to be between the two halves of the other,
The full electrotonic effects, both stimulating and inhibitory, are produced at	The electrotonic effects are propor-

each electrode, and the law of contractions is based upon (1) the greater stimulating power of appearing katelectrotonus, (2) the interference of appearing anelectrotonus and of the negative variation of disappearing katelectrotonus.

tional to these densities, and the order and time of contractions depends upon (1) the greater stimulating power of katelectrotonus, (2) the relative density at the virtual electrodes.

In both instances the condition of vitality of the nerve will of course have to be considered as influencing the results. In experiments on the prepared frog's nerve it has long been noted that numerous circumstances, some connected with the process of exsection, others independent from it, exerted a disturbing influence on the results. In many cases these circumstances may be explained on the grounds that where-ever the homogeneity of the nerve-fibres is destroyed a secondary anode and kathode exists. Even points where a considerable nerve-branch is given off by a nerve may set up such secondary electrodes, owing to the sudden change in the diameter of the nerve, and perhaps in the relative distribution of the connective tissue, which, of course, is to be looked upon as a different electrolyte from the nerve-fibres.[1] Again, in arguing from unipolar experiments on frogs, a possible source of fallacy may be found in the difference between the relative conductivity of nerve and muscle (and other tissues) in that animal and that obtaining in man: a condition which would materially alter the relative densities of the virtual anodes, under apparently similar circumstances. Any attempt then, I repeat, at *reconciliation* between the unipolar method of the electro-therapeutist and the bipolar method of the physiologist is, strictly speaking, meaningless, for there is nothing to reconcile; they start from the same fundamental axiom. The moment the different conditions under which they act in each case are explained the whole question is as clear as we can wish. In the bipolar method there is an element which does not exist in the unipolar: that of the *inhibitory*[2] effect of the lower pole on the influence of the upper pole. This effect comes into play only in the third stage of Pflüger's law, where the incipient anelectrotonus arrests the katelectrotonic impulse at the closure of the ascending current, and the negative

[1] Hering ('Sitzungsberichte d. K. K. Akad. d. Wissenschaften,' lxxix.) makes similar observations with reference to muscle.

[2] 'Sit venia verbo!'

modification arrests the anelectrotonic stimulation at the opening of the descending current. Trying to find anything similar when the unipolar method is used is a contradiction in terms, a begging of the whole question, and we have seen that Filehne's experiments on the subject are open to grave suspicion.

With reference to the experiments on the production of electrotonus in the human subject, it may be fairly said that they have led to very scanty results, and are exposed to a fundamental objection: that of the summation of the effects of the polarising and testing currents. But do we need any such experiments in order to estimate the electrotonic condition of any nerve? Is not the occurrence of opening and closure contractions, the best proof of the existence of anelectrotonus and of katelectrotonus? Taking the occurrence, then, of these contractions as an index to the condition to the polarised nerve, the obvious conclusion is that it is very rarely indeed, and on a very small scale, that we can ever produce anything like a pure anelectrotonus. In almost every position of the actual positive electrode, we obtain A.C.C > A.O.C.: a proof that the virtual kathode overpowers the virtual anode, that the katelectrotonus predominates over the anelectrotonus. The practical conclusion from this fact is that a therapeutical system built on the opposite anelectrotonic and katelectrotonic effects rest upon an imaginary basis. In by far the great majority of cases we can produce only predominant katelectrotonus; that is katelectrotonus with a more or less considerable admixture of anelectrotonus in its immediate neighbourhood. When to this consideration we add the fact that anelectrotonus immediately passes, on breaking the current, into a phase of increased irritability (positive modification) it is difficult to understand the precepts so often given that "the positive pole acts as a sedative, the negative as a stimulant." Both are stimulants, if "stimulation" there be, the kathode more so than the anode; but that is all, and I demur to the charge of inconsistency brought by Erb against those who, adopting the unipolar method for purposes of diagnosis, do not carry it out systematically in therapeutics. A further objection to the electrotonic system of electro-therapeutics is that in the only instance where we can produce pure polar effects, in that of the acoustic nerve, "the systematic production of an- or katelectrotonus," as it is called, has not proved a success. Indeed, if the doctrine were true, we might expect that where the negative pole is indicated the positive would increase the mischief, and *vice versa*. It is a matter of daily experience that hyperæsthesic, hyperalgesic, and hypercinesic symptoms are, as a rule, happily influenced by the one pole as by the other. As to the pretension of inducing electrotonus of the brain, spinal cord, and vaso-motor nerves (katelectrotonus of the latter, by the way, to produce *dilatation* of the arterioles), I do not know upon what physiological evidence it rests, nor even what the expression very well means.

Though the unipolar method does not fulfil therapeutically the ambition of its promoters, its adoption has led to most valuable results in the field of diagnosis, and I am the more anxious to recognise Brenner's durable services in this respect that I have been led to stand in antagonism to his other views. Electro-diagnosis, difficult enough on this unipolar system, is impossible on the bipolar method, with which in the living subject we would get *four* electrodes to the same nerve; and the bitterest foes of the new system have been obliged to adopt it, though not always with the best grace.[1] A clear conception of the physical conditions of unipolar stimulation is, however, necessary for the rational application of electrical tests, and I am not without hope that the previous remarks may clear up certain obscurities hitherto prevalent.[2]

The question of a possible influence of the direction of the current is intimately bound up with that of the density of the current. On this point, again, much useless discussion has been expended. Supposing it is desired to estimate how much electricity passes through the sciatic nerve at a point halfway between the glutæal region to the popliteal space when the electrodes with a current of say twenty millevebers[3] are

[1] Cf. Benedikt, 'Elektrotherapie,' 2nd Ed. 1874.

[2] When the electrode is placed on the abductor indicis near its insertion, I find that A.C.C. > K.C.C. The same phenomenon occurs in other parts, and is explainable on the assumption that a virtual kathode occurs at a point of the muscle more excitable than the point of application of the anode.

[3] De Watteville, 'Practical Introduction to Medical Electricity,' chap. i. A current of 20 millivebers would be given here by about 40 Daniells.

placed in these positions, all we shall have to do is to divide the diameter × specific resistance of the nerve by the diameter × mean specific resistance of the tissues of the thigh. The equation $\frac{D \times R,}{D^1 \times R^1} = \frac{X}{20}$ gives us the result. Assuming $D^1 = 12$ and $R^1 = 5$, when D and R are taken at unity this would give us $\frac{1}{60}$th of the current as passing through the nerve at the point, which is a very high estimate. This rough calculation gives us at least as accurate quantitative results as the galvanometric experiments of Burkhardt[1] and others, since the unknown relation between the resistance of the piece of nerve included between the needles and that of the galvanometer used can hardly be determined. This is not the place to discuss the arguments adduced by those who uphold the influence of the direction of the currents on the various tissues.[2] They cannot escape the objections deduced from the fact of a peripolar direction of the current in the nerve and from the great diffusion of the current in the interpolar region; it is only within a short radius of each electrode that the density is sufficiently great to produce physiological effects. And though the therapeutical conditions drawn from the electrotonic influence of the poles are not justified, it has yet to be shown that the very weak currents which traverse the tissues at a distance from the electrodes have any curative power, apart from any demonstrable physiological action. This supposition is, of course, within the range of possibility; but the partisans of direction-influence have hitherto produced no proof that their results do not depend from the relative position of the poles. The discussion of this point will be best deferred to another occasion.

If these pages, as I hope, have shaken one of the many *Idola Specûs* of electro-therapeutics, and disposed of some of the loose talk and thought so rife in the literature of the subject, my object is fulfilled.

1 "Die polare Methode," 'Deutsches Archiv,' 1870.

2 Onimus and Legros, 'Traité d'Électricité médicale,' Paris, 1872.

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